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Promotion of Flowering in Western Larch by Girdling and Gibberellin $A_{4/7}$ and Recommendations for Selection and Treatment of Seed Trees

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SUMMARY

Different combinations of stem girdles and gibberellin $A_{4/7}$ ($GA_{4/7}$) stem injections were tested on 17-year-old western larch (*Larix occidentalis*) in a provenance trial near Enderby, B.C. Trees that failed to flower without treatment produced an average 5 seed cones and 16 pollen cones each in response to stem injections of $GA_{4/7}$, at flushing of the long shoots and again 2 weeks later. The six B.C. western larch provenances in this trial differed greatly in their flowering response to $GA_{4/7}$. Girdling was ineffective in promotion of flowering, either alone or in combination with $GA_{4/7}$. Recommendations are made for the selection and treatment of seed production areas as an interim measure until clonal seed orchards come into production.

Relative to the field-grown trees, potted grafts only 3 years old flowered profusely following a spring root pruning by root weevils. Although not recommended as an induction treatment, this response to root damage is evidence that western larch may be a good prospect for container seed orchards. The potted trees have provided experimental material for much-needed research on pollination and seed development, as well as on the tissue-culture production of haploid plants for this species.

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INTRODUCTION

In its natural range on western slopes of the Rocky Mountains in southern British Columbia and the northwestern United States, western larch (*Larix occidentalis* Nutt.) is highly valued for its rapid growth, high quality wood and resistance to root diseases (Schmidt *et al.* 1983). However, attempts to regenerate the species are hampered by chronic shortages of good quality seed (Shearer and Schmidt 1987). In 1987, the B.C. Ministry of Forests began selection and propagation of parent trees for the establishment of seed orchards to address seed supply shortages (Jaquish 1987). Open-pollinated seed was also collected from the parents as a basis for a breeding program.

Western larch in natural stands flowers infrequently before 25 years of age (Owens and Molder 1979b). Thereafter, good cone crops occur on average every 5 years, although this may range from 1 to 12 years depending on site and stand conditions. Shearer (1986) reported that seed production by western larch averaged only two-thirds that of similar-size interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) growing in the same stands in western Montana. Western larch is also characterized by having very poor seed set, with typically only 5–10 filled seeds per cone (100–120 total) (Shearer 1984), compared to 30–40 for Douglas-fir (70–80 total). Thus, it appears that cone enhancement is necessary for western larch if breeding is to be completed in a timely manner and seed orchards are to be productive.

Little work has been aimed at enhancing flowering in western larch. Shearer and Schmidt (1987) demonstrated the importance of adequate spacing to ensure good crown development (hence, potential flowering sites) and exposure to full sunlight (hence, realization of that potential). Seed-cone production by 30-year-old trees in natural stands thinned at age 8 years to a spacing of 6.1 × 6.1 m was 10-fold that at a 2 × 2 m spacing. Pollen-cone production was enhanced even more at the wider spacing.

Girdling is generally an effective treatment for promoting female and male flowering in other larches (see Bonnet-Masimbert (1982) references), and two studies suggest its effectiveness also on western larch. Graham (1986) tested stem girdles, ammonium-nitrate fertilizer, and the two treatments combined on 70-year-old western larch in a natural stand in Idaho. Girdling alone increased the mean production of seed cones from 77 to 832 per tree. Fertilization had no effect by itself (86 cones per tree), and it negated the promotive effect of girdling when applied with that treatment (16 cones per tree).

Prill (1990) compared similar treatments in a preliminary study on 90-year-old western larch in a natural stand near Grand Forks, B.C. Although the sample size was small (four to five trees per treatment) and the variation among trees was large, he also found evidence for a significant increase in seed-cone production from girdling. Unlike the previous study, ammonium-nitrate also promoted flowering, especially in combination with girdling. As with Douglas-fir (Ebell 1972), however, the urea form of nitrogen inhibited cone production.

The effectiveness of exogenous applied gibberellins (GAs), a natural plant hormone, for promoting earlier and enhanced flowering in conifers is well established (Pharis *et al.* 1987). The few studies that have been conducted on larches, however, have given inconsistent results. Hashizume (1973) reported enhanced flowering (mainly males) following treatment of 7-year-old Japanese larch (*Larix leptolepis* Gord.) with GA_3. In another study on 9-year-old Japanese larch (Katsuta *et al.* 1981), neither GA_3 nor $GA_{4/7}$ treatments was effective, but the trees responded positively to girdling. Working with 7-year-old seedlings of Japanese and European larch (*Larix decidua* Mill.), Bonnet-Masimbert (1982) reported 8- and 2-fold increases in female and male flowering, respectively, from the $GA_{4/7}$ treatment, and again the response was enhanced by girdling.

This paper reports on the flowering response by young plantation-grown western larch to $GA_{4/7}$ stem injections and stem girdles, each alone and in combination, versus no treatment. Recommendations are provided for the selection and treatment of seed production areas as an interim measure until such time as clonal seed orchards come into production during the mid- to late-1990's (Jaquish 1987). The potential for containerized orchards is discussed as well.

MATERIALS AND METHODS

Seventeen-year-old trees in block "A" of the Trinity Valley western larch provenance trial, located 17 km west of Enderby, B.C. at an elevation of 600 m, were used for this study. Six British Columbia provenances (see Table 4), each consisting of a single 5 × 5 tree plot planted at a 3 × 3 m spacing, are represented. Through mortality, the original 25 trees per provenance has been reduced to between 24 and 17 trees.

From among the six provenances, 120 vigorous and non-forked trees, 4- to 15-cm diameters at 1.2 m above ground (DBH), were selected in early spring 1989. Trees were ranked in order of increasing DBH and then divided into groups of four, one tree of which was randomly assigned to each of four treatments: 1) no treatment; 2) girdles only; 3) $GA_{4/7}$ only; and 4) girdles + $GA_{4/7}$. The 30 trees per treatment thus had a similar distribution of DBH's and random representation of provenances.

Double-overlapping stem girdles (Wheeler *et al.* 1985) were timed (26 April) to coincide with the flushing (i.e., needle emergence) of dwarf shoots. Girdles were made with a pruning saw, severing the bark to the depth of the cambial zone (determined by the change in density from soft, easily cut bark to more dense wood). Each girdle extended approximately 60% around the stem circumference: the uppermost girdle at a height of about 1.2 m above ground, the second girdle on the opposite side of the stem at a distance from the first equal to the stem diameter.

The $GA_{4/7}$ was applied by pulsed stem injection, an economical method of proven effectiveness safe for use on other conifers (Philipson 1985; Longman *et al.* 1986; Ross and Bower 1989, 1990). The first of two $GA_{4/7}$ injections was made on 12 May when the long shoots of approximately 85% of the trees had flushed. The second injection was 2 weeks later. The $GA_{4/7}$, dissolved in 95% ethyl alcohol at 30 mg mL^{-1}, was injected into ¼-inch (6-mm) holes bored around the stem with a portable electric drill. Holes were 30-mm deep, drilled at a downward angle to prevent spillage of the injected solution. The $GA_{4/7}$ dose was adjusted to tree size (DBH) by varying the number of holes (evenly spaced around the stem) and volume of $GA_{4/7}$ solution injected per hole on each date as shown in Table 1. New holes were drilled each date, the first set at a height of 1.4 m (20 cm above the uppermost girdle, if present), the second set at 5 cm above and midway between the first. Following injection, holes were plugged with a short length of ¼-inch (6-mm) wood dowel.

Seed and pollen cones produced as a result of treatment or lack of treatment in 1989 were counted shortly after emergence in spring 1990. A high frequency of non-flowering trees associated with certain treatments and provenances resulted in large and unequal variances among treatments in numbers of cones per tree. Data were therefore subjected to a nonparametric two-way ($GA_{4/7}$, girdling) analysis of variance by ranks (Conover 1980), using DBH as a covariate to adjust for differences in tree size.

TABLE 1. Number of injection holes and volume of $GA_{4/7}$ (30 mg.mL^{-1} in 95% ethanol) injected per hole on each of two dates (new injection holes were drilled each time) for western larch trees of different stem diameters (DBH). The last column gives the total amount of $GA_{4/7}$ applied over both dates to each tree

Stem DBH (cm)	Holes/tree (no.)	Solution/hole (mL)	Total $GA_{4/7}$ (mg)
4–5	2	0.5	60
6–7	2	0.75	90
8–10	2	1.00	120
11–12	3	0.85	150
13–15	3	1.00	180

RESULTS

Flowering responses to treatment were similar whether expressed as the percentage of trees bearing seed and pollen cones (Table 2) or the mean number of cones per treated tree (Figure 1). Table 3 summarizes results of the analysis of variance on the rank-transformed cone counts.

The study was conducted in a year (1989) when climatic conditions (temperature, precipitation etc.) were apparently unfavorable for differentiation of cone buds. Whereas 23% of trees in the plantation showed evidence of past cone production, none of the untreated trees produced seed or pollen cones in 1990. Treatment with $GA_{4/7}$ alone significantly (Table 3) promoted both female and male flowering. Thus, 50% of the $GA_{4/7}$-treated trees initiated seed cones and 23% produced pollen cones (Table 2), an average of 5.3 and 16 each, respectively (Figure 1).

TABLE 2. Percentage of trees producing seed and pollen cones in 1990 following girdling and $GA_{4/7}$ treatments in 1989 (n = 30)

Treatment	Seed cones	Pollen cones
Untreated control	0	0
Girdles only	7	3
$GA_{4/7}$ injections only	50	23
Girdles+$GA_{4/7}$	40	20

TABLE 3. Summary of analysis of covariance on rank-transformed cone counts[a]

Source of variation	DF	Seed cones		Pollen cones	
		SS	P	SS	P
DBH	1	3337	0.010	6722	<0.001
Girdling (G)	1	14	0.938	9	0.867
$GA_{4/7}$	1	19596	<0.001	3635	<0.001
G × $GA_{4/7}$	1	512	0.310	333	0.306
Error	114	56181		35954	
Total	**118**	**79650**		**46684**	

[a] SS = sums of squares; P = the probability of type I error for listed effect.

Girdling alone did not increase the percentage of trees bearing seed or pollen cones, and in this regard the girdling + $GA_{4/7}$ was not better than $GA_{4/7}$ alone (Table 2). Based on cone production (Figure 1), girdling appeared to enhance the female and depress the male flowering response to $GA_{4/7}$, but neither effect was significant (Table 3).

The $GA_{4/7}$ treatment was slightly phytotoxic, whereas girdling had no discernable effect on tree condition. This phytotoxicity was confined to the terminal shoot where the distal 25–50% directly killed. The $GA_{4/7}$-treated trees otherwise appeared healthy.

Large differences in the flowering response (female and male) to $GA_{4/7}$ were noted for trees of the six British Columbia provenances of western larch (Table 4). In this study, however, genetic and source-of-origin effects are confounded by the fact that each provenance occupied a somewhat different microsite along a 135-m E-W transect which extended from ridge top to near the base of a 10–15° north-facing slope. The most

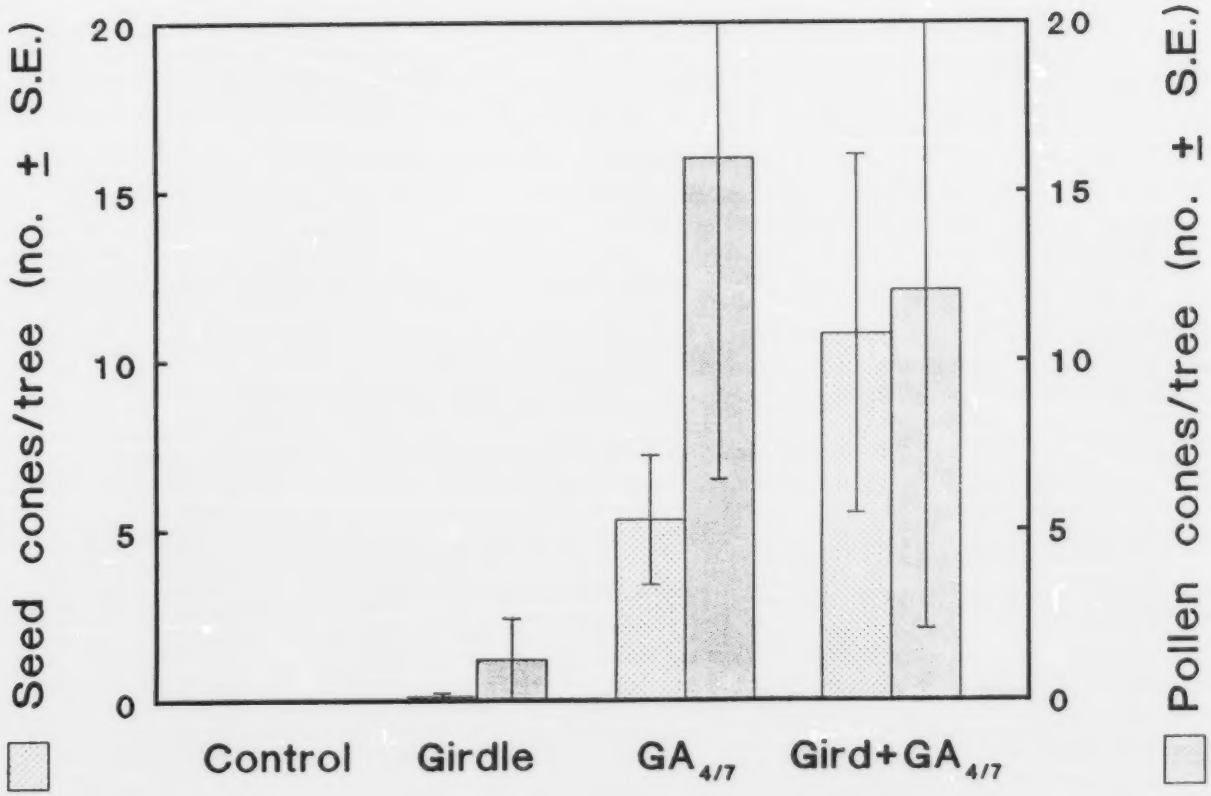

FIGURE 1. Mean production of seed and pollen cones in 1990 following girdling and $GA_{4/7}$ treatments in 1989.

fecund provenance (for female as well as male flowering). Salmon Arm, was situated at the top of the ridge. There the shallower, more droughty soils may have lead to water deficits more conducive to flowering. Otherwise, there was no apparent relationship between flowering and the provenance's location along the slope (Table 4). Nor, except for Salmon Arm, was there a relationship between female and male fecundity.

TABLE 4. Mean production (± standard error) of seed and pollen cones by $GA_{4/7}$-treated trees of six western larch provenances planted near Enderby, B.C.

Provenance[a]	Origin			Cones/tree (no. ± se)	
	Lat.	Long.	Elev. (m)	Seed	Pollen
Salmon Arm	50°40'	119°10'	800	14 ± 6	73 ± 13
Crystal	49°28'	119°00'	1200	7 ± 5	6 ± 10
Benton Creek	49°12'	117°21'	1150	3 ± 5	2 ± 2
Tillicum	49°08'	117°02'	1500	9 ± 5	0
Boundary Creek	49°22'	118°38'	1500	6 ± 5	0
Rossland	49°10'	117°46'	1200	14 ± 9	24 ± 12

[a] Provenances are listed according to their position from ridge top to base of a north-facing slope.

DISCUSSION

The increased production of seed and pollen cones by these young western larch trees from stem injections of $GA_{4/7}$ (Figure 1) was highly significant (Table 3). Nevertheless, the increases were small in relation to those reported for similar-size. but sexually mature grafts of Sitka and interior spruce (Philipson 1985; Longman *et al*. 1986; Ross 1990a,b), Douglas-fir (Ross and Bower 1989, 1990), and western hemlock (Parkinson 1989). The lack of response to girdling is surprising as in these other studies the treatment has generally promoted flowering, especially when applied in combination with $GA_{4/7}$.

Several reasons likely explain the relatively small response to $GA_{4/7}$ and girdling in this study. Western larch has a long juvenile phase of purely vegetative development that in natural stands may last for up to 25 years (Owens and Molder 1979b). Although about a quarter of the study trees had flowered previously, at 17 years from seed they may have yet to attain full sexual maturity. More importantly, perhaps, the Trinity Valley plantation was neither managed for nor located on a site that is particularly conducive to flowering, as evidenced by the lack of cones on mature trees in adjacent stands. And, as previously noted, climatic conditions during the year of treatment were apparently less favorable than normal.

Exposure to sunlight is important for good flowering (Shearer and Schmidt 1987), and it appears that at the original spacing of 3 × 3 m, light and/or associated temperatures had reached suboptimal levels. As is typical for the species (Owens and Molder 1979b; Shearer and Schmidt 1987), seed cones tended to be confined to the uppermost crown. Trees whose neighbors, especially to the south and west, were missing tended to produce more seed and pollen cones in response to $GA_{4/7}$ treatment. These cones were also borne lower on the exposed region of the crown. As reported by Bonnet-Masimbert (1982), treatment with $GA_{4/7}$ also extended the zone of female and male flowering lower, where the cones are more easily harvested.

The present findings are encouraging in showing the flowering response that might be expected in a properly located and managed western larch seed orchard made up of sexually mature grafts. The $GA_{4/7}$ treatment was slightly phytotoxic in causing partial dieback of the stem terminal shoot. However, even this may be viewed as beneficial in providing a degree of height control. Finally, it is possible that in this initial study on western larch the timing and dosage of $GA_{4/7}$ used may not have been optimal for promotion of flowering.

Bonnet-Masimbert (1982) compared branch applications of $GA_{4/7}$ applied at different times (April through August) on Japanese and European larch seedlings growing in France. For both species, May-June applications maximized male flowering, and June-July applications maximized female flowering. Unfortunately, treatments were timed to calendar date rather than to stage of shoot or bud development, which is the critical factor. Thus, these results cannot be directly extrapolated to western larch growing in a different climate.

Timing of $GA_{4/7}$ injections in the present study was based on work by Owens and Molder (1979a,b), who found that the differentiation of seed and pollen cones on vegetative short (dwarf) shoots in western larch coincides with the end of vegetative long shoot elongation. Since other studies show that $GA_{4/7}$ treatment should precede actual cone-bud differentiation by at least several weeks (Ross 1983; Marquard and Hanover 1984), the $GA_{4/7}$ was injected when the long shoot flushed, and 2 weeks later. Eysteinsson and Greenwood (1990) recently reported for eastern larch (*Larix laricina* (Du Roi) K. Koch) that $GA_{4/7}$ applications starting at flushing of long shoots were significantly more effective in promotion of female flowering than treatments which began 2 or 3 weeks later. Earlier treatments, which might have been even more effective, especially in promoting male flowering (Bonnet-Masimbert 1982), were not tested.

A $GA_{4/7}$-timing experiment using potted 3-year-old western larch grafts was also scheduled for 1989, but not implemented. When repotted that spring, the otherwise healthy-appearing trees were found to have suffered severe damage from root weevils. Despite chemical treatment (Orthene soil drenches) and physical removal of grubs, over 60% of the trees died as a result of the root pruning. Those that survived, however, flowered profusely the following year (Figure 2), and at this writing are healthy. Ramets of all 10 clones flowered, producing an average of 18 and 82 seed and pollen cones each, respectively.

Although such severe root pruning cannot be recommended as a cone-enhancement treatment, these results indicate that western larch may be an ideal candidate for container seed orchards (Ross *et al.* 1986). Eysteinsson and Greenwood (1990) have shown that similarly profuse female and male flowering can be induced in young, potted eastern larch by heat and properly timed $GA_{4/7}$ treatments. Container orchards offer advantages for western larch in addition to those usually cited (Ross *et al.* 1986): earlier, more abundant flowering, better control of pollen parentage for improved genetic gains, and overall convenience of management.

Because the seed and pollen cones of larch emerge earlier in spring than is the case for most other conifers, and thus are highly susceptible to killing frosts (Shearer 1984; Lewandowski and Kosinski 1987), the protection afforded potted trees within a polyhouse could be critical. Lack of pollen may also be a major reason for the low seed set seen in field-grown western larch (Shearer 1984; Prill 1990). Results of the present study suggest that the poor pollen production typical of natural stands can be remedied somewhat in seed orchards by proper management and induction treatment. Even so, the yield of pollen per cone is very low in western larch, averaging only 9 µL per bud for the potted grafts versus 74 µL per bud for interior spruce (Ross 1989). Therefore, supplemental pollination, which is most efficiently undertaken on small, potted trees in polyhouses, will likely be mandatory for good seed set in western larch.

The potted trees that flowered so profusely in response to an accidental root pruning have provided experimental material for colleagues researching pollen and seed development in western larch. Dr. J.E. Webber (Research Branch) has sampled the pollen (84 mL were collected from 9626 buds) and found it to be highly viable on the basis of *in vitro* conductivity and respiration measurements. Optimal time of pollination is being investigated by Dr. J.N. Owens of the University of Victoria. His study will also provide basic information on *in vivo* germination of pollen and seed development under near optimal conditions.

In addition, Dr. P. von Aderkas, also of the University of Victoria, has collected unfertilized ovules at various stages of development for research on tissue-culture production of homozygous haploid plants. If successful, the technique would offer an invaluable tool for rapidly fixing desirable genes and eliminating deleterious ones in purebred lines. These lines could then be mass-produced either vegetatively through tissue culture or rooted cuttings, or by normal sexual reproduction in container or field orchards.

FIGURE 2. Profuse female flowering by potted 4-year-old western larch in the polyhouse in response to severe root pruning by root weevils the previous spring. These trees also produced abundant pollen cones, which were picked before this photograph was taken (May, 1990).

RECOMMENDATIONS FOR SELECTION AND TREATMENT OF SEED TREES

The establishment of western larch seed orchards in British Columbia only began in 1987, and these orchards will not begin to satisfy the increasing seed demand for another 7–10 years. If established now, container orchards might meet this demand sooner, but the question still remains of what to do during the interim. One option is the establishment of seed-production areas (SPA's) in natural stands. Although the experience with SPA's for other British Columbia conifers is not very encouraging (Konishi 1986), several steps can be taken to maximize the probability of success.

Two basic production options

Embodied in the SPA concept is 1) selecting a phenotypically good stand of appropriate provenance on a reasonably good site for flowering; 2) thinning it to the best individuals (phenotypes); which 3) are then managed (usually extensively) for more or less sustained seed production. However, western larch is frequently regenerated by seed trees, and this silvicultural system provides a second option for producing seed beyond that required to replace the stand. The seed trees may be induced to flower, as discussed below, the year before their scheduled removal, and then felled prior to seed dispersal so that cones can be easily collected from the ground.

There are both pros and cons to this latter approach. If conditions are favorable in the year of application so that treatments are effective, it can be an inexpensive approach to seed production. The generally larger size of trees left as seed trees relative to those in a typical SPA should have a greater cone-bearing potential. However, whereas SPA's should be located on reasonably good sites for flowering, this often will not be true for seed-tree stands. In this case the induction treatments may be relatively ineffective. And, as discussed below, the $GA_{4/7}$ treatment itself will probably not be nearly as effective on the larger trees retained for seed production. Finally, the presence of any advanced regeneration can limit the use of other induction treatments, such as excessive application of nitrogen, which may adversely affect their performance.

While the treatment of seed-tree stands is an option, it is one perhaps best suited for ensuring regeneration of the stand being removed rather than for producing surplus seed for harvest. For this purpose we recommend a properly sited and managed SPA. The following recommendations, though specific to that objective, also apply to the treatment of seed-tree stands.

Stand Selection

In selecting a stand for use as a SPA the principal considerations (in decreasing order of importance) are site, age and vigor of trees, area and stocking level, and convenience of operations. The selection process should also include consultation with the western larch tree breeder (Barry Jaquish, Kalamalka Research Station) to ensure that the provenance is suitable for the intended planting area.

Site: Site is the single most important factor in determining the potential for seed production. In comparing natural stands of western larch in western Montana, Shearer and Schmidt (1987) reported significantly better flowering for similar-aged trees on good than on poor growing sites. However, this is probably because trees at the same age were larger on good sites and, hence, possessed more potential sites for flowering. The greater body of experience, mostly from seed orchards and older stands, is that good growing sites are generally not the best sites for seed production (Konishi 1986).

Stands to look for are those on warm, relatively dry sites at lower elevations, where favorable water deficits can be reasonably expected to occur during cone-bud differentiation, and the chance of killing frosts at cone emergence in spring is small. The best criterion is evidence of good cone production in years past. Particular attention should be paid to older dominant and open-grown trees in the immediate area, as their performance will best reflect the site's potential for producing cones.

Tree age and vigor: Prospective seed trees should be at least 30 years of age, with well-developed crowns, to have a reasonable chance of producing sufficient cones to make the effort worthwhile. Other factors being equal, the larger the tree the greater its capacity for cone production. However, very large trees may not be very amenable to cone enhancement, and the cones produced are costly to harvest. Although

girdling can be applied to trees of any size, the upper practical limit for the more effective $GA_{4/7}$ treatment seems to be about 40 cm DBH. Priority should be given to younger stands whose co-dominant and dominant western larch are between 20 and 30 cm DBH.

Stand size and stocking level: Size of the SPA is determined not only by the desired average annual seed yield, but also by the need for adequate pollen to ensure good seed set. A Douglas-fir seed orchard requires an area of at least 4 ha to provide a pollen cloud of adequate density for good seed set (J.E. Webber, pers. comm.). Western larch, as previously noted, is a much less prolific producer of pollen, and pollen production in an SPA is likely to be much lower than in a well-managed seed orchard. It is therefore recommended that SPA's of western larch be at least 10–15 ha in size.

Western larch typically grows in mixture with other conifers. The larch component must be sufficient to warrant operations, and yet the total stems per hectare for all species must also not be so great that past competition has severely restricted crown development on the potential seed trees. Following thinning and spacing, the selected stand should contain between 50 and 100 dominant and co-dominant stems of 20–40 cm DBH per hectare.

Thinning and Spacing

Once the stand has been selected, it must be prepared for seed production. The first step is to select the seed trees and remove all others. After thinning, the remaining seed trees should be spaced far enough apart so that the entire live crown is free from competition and fully exposed to sunlight. Depending on how long the SPA is to be in operation, subsequent thinning may be required to ensure this condition is maintained.

The selected seed trees should have vigorous, well-developed crowns capable of producing abundant seed and pollen cones. The girdling and $GA_{4/7}$ treatments are most effectively applied at the base of the live crown, so the nearer the crown extends to the ground the better. "Wolf" trees with coarse and otherwise undesirable branching characteristics, and trees with crooked or forked stems, should be avoided as these traits tend to be highly heritable. In other words, the seed trees should be good phenotypes.

Fertilization

Fertilization can play both a direct and indirect role in promoting flowering (Ross and Pharis 1985). It can, under certain circumstances, be an effective cone-enhancement treatment in its own right, and guidelines for its use for that purpose follow. In addition, under site conditions where nutrient availability is limiting for growth, crown development—and hence potential sites for flowering—is enhanced by application of appropriate fertilizers.

Foliar samples should be taken for nutrient analysis at the time the stand is selected, and periodically (3–5 years) thereafter, so that appropriate fertilizer(s) may be applied to remedy any nutrient deficiencies discovered. This analytical service is provided by the B.C. Ministry of Forests (1989). The fertilizer(s) should be applied at a frequency (typically 2–5 years) and rate sufficient to ensure good but not luxuriant vegetative development, as excessive growth can also be deleterious to flowering.

Cone-Enhancement Treatment

Except where trees are very large (>40 cm DBH), it appears that stem injection of $GA_{4/7}$ will be the best single treatment for promoting flowering in western larch. Although not clearly demonstrated in the present study, the effectiveness of $GA_{4/7}$ is frequently enhanced when applied in conjunction with girdling. Despite the negative results by Graham (1986), there is evidence (Ross *et al.* 1981) that nitrogen (N) fertilization as well can be a beneficial adjunct to $GA_{4/7}$. Procedures for applying these treatments are given in the following sections.

For trees too large to efficiently treat by $GA_{4/7}$ stem injection, a combined treatment of girdling and N-fertilization is worth considering. However, because three-way treatments can be overly stressful, only one or the other, not both, should be used with $GA_{4/7}$. The optimal treatment combination is likely to be different for different sites and trees of different ages. It is thus worth determining experimentally, for each SPA, which adjunct to $GA_{4/7}$ is best, or even beneficial. The author can assist in designing trials to determine this.

Individual trees should be treated no more frequently than every other year. A year of rest between induction attempts allows for vegetative recovery (i.e., replenishment of short shoots turned reproductive), and also avoids possible deleterious effects of the induction treatment on developing cones and seed. Trees bearing abundant cones similarly should not be treated. Otherwise, it is recommended that only half the trees per stand be treated each year on an alternate-year basis. Although this may be inconvenient for stands not readily accessible, it will ensure that not all trees are treated in a year that climatic conditions are so unfavorable as to negate the treatment's effectiveness.

$GA_{4/7}$ injection: Work with other species (Parkinson 1989; Ross and Bower 1990; Ross 1990b) suggests that a single, properly timed injection of $GA_{4/7}$ will be nearly as effective and significantly less costly than the two injections used in the study reported on here. This injection should be made when the long shoots on approximately 50% of the trees have flushed in spring.

The recommended $GA_{4/7}$[1] dosage for trees of 16–40 cm, in 5-cm classes, is given in Table 5 (for trees smaller than this, the dosages listed in Table 1 should be used). These amounts are extrapolated from results on Douglas-fir (Ross and Bower 1989), for which the optimal $GA_{4/7}$ dosage is about 60 mg/14 cm of stem circumference. Otherwise, procedures for drilling and injecting[2] trees given in the Methods section should be followed.

To prepare the $GA_{4/7}$ solution, the following steps are recommended. First determine the number of trees of each diameter class to be treated, and add up the number of injection holes from Table 5. Multiply this number by 0.5 mL (the volume of alcohol/hole), adding 15–20% for spillage and evaporation, to give the total volume (in mL) of alcohol[3] required. Weigh out and dissolve in the alcohol (by stirring at room temperature) an amount of $GA_{4/7}$ equal to the product of 60 mg times the volume of alcohol in millilitres. This solution may be stored for up to several months in the refrigerator.

TABLE 5. Recommended number of injection holes and total $GA_{4/7}$ dosages for western larch seed trees of different diameter classes. Into each hole of ¼-inch diameter is injected 60 mg $GA_{4/7}$ in 0.5 mL alcohol at flushing of long shoots in spring

Tree DBH class (mm)	Injection holes/tree (no.)	$GA_{4/7}$/tree (mg)
16–20	4	240
21–25	5	300
26–30	6	360
21–35	7	420
36–40	8	480

Girdling: The procedure for this treatment—applied at flushing of dwarf shoots, which precedes flushing of long shoots, and $GA_{4/7}$ treatment, by 3 to 5 weeks—is given in the Methods section. Assuming that trees will be girdled biennially at least several times, the upper girdle of the first treatment (which is separated from the lower girdle by a distance equal to the stem diameter at that point) should be positioned relatively low on the stem. This is for convenience, as the upper girdle of each subsequent biennial treatment will be applied 10 cm above the upper girdle of the previous treatment, with its gap (uncut portion) offset 90° from these.

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[1] By patent agreement with the manufacturer (ICI Ltd., UK), $GA_{4/7}$ for forestry-related use in North America may be purchased from Dr. R.P. Pharis, Department of Biology, University of Calgary, Alberta, Canada T2N 1N4 (phone: 403-220-5259). The 1990 price (Canadian) is $15.00 per gram plus $25 handling and shipping. Orders should be placed at least 3–4 months in advance. The $GA_{4/7}$ powder retains its biological activity for many years when stored at –15°C in a sealed container.

[2] An automatic refilling pipet, such as the 2-mL Cornwall syringe pipet (Cat. No. BD3052) sold by Johns Scientific Inc. (phone 800-661-8525), is recommended. It should be thoroughly cleaned in alcohol after use.

[3] Instead of ethyl (grain) alcohol, which requires a special tax permit, isopropyl (rubbing) or methyl (wood) alcohol can be used to dissolve the $GA_{4/7}$.

After several treatments it may be necessary to adjust this spacing to ensure that the new girdle (upper or lower) does not overlap a previous girdle. Although chain saws have been used to girdle large trees with thick bark (see Graham 1986), a pruning saw is safer (both for tree and operator) for trees of 40 cm DBH and less, especially where trees are to be girdled more than once.

N-fertilization: Nitrogen is the only element known to promote flowering in conifers, and the form of N is important (Ebell 1972). Both calcium-nitrate and ammonium-nitrate can be effective, but the latter, being less expensive, is recommended. Urea forms of N, which have been found in some studies to be deleterious to flowering, should be avoided.

Application of ammonium-nitrate for cone induction should coincide with flushing of the long shoots (i.e., with $GA_{4/7}$ treatment). The fertilizer should be applied as a narrow band around the drip line of each tree at a rate equivalent to 600 kg ammonium-nitrate ha^{-1} (200 kg N ha^{-1}), based on the area within the drip line as determined for trees of average crown spread.

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